# DIGITAL Ultrasonic Delay Lines

ADVANCED COMPONENTS

LFE ELECTRONICS

A DIVISION OF LABORATORY FOR ELECTRONICS, INC.

BOSTON, MASSACHUSETTS

*EVOLUTION OF THE DIGITAL ULTRASONIC DELAY LINE*

*With the advent of present-day, high-speed miniaturized computer circuitry, many conventional serial memory devices — such as magnetic drums, tapes and discs, and magnetostrictive delay lines — have been rendered almost obsolete. In effect, the search for memory devices compatible with such circuitry has resulted in the development of a new family of solid-state delay devices, based on conventional ultrasonic delay line technology — Digital Ultrasonic Delay Lines. Unlike conventional ultrasonic delay lines, these devices are designed to:*

- *Operate without an RF carrier;*
- *Handle digital data in the form of video pulses, and;*
- *Provide minimum distortion and loss.*

*Bit rates from 0.5 to 40 megacycles, with storage capacities well in excess of 20,000 bits, are presently achievable. The basic theory and processes involved in the design of digital delay lines, as well as typical parameters, applications, test methods and specification procedures, are outlined in the following paragraphs.*

## SOLID ULTRASONIC DELAY LINES

Ultrasonic delay lines make use of the relatively slow velocity of acoustic waves through dense solid media to achieve long delays in relatively small space. The electrical signals to be delayed are converted into acoustic waves by the input transducer affixed to the delay medium (see Figure 1). Upon reaching the output transducer, the acoustic signal is reconverted into an electrical signal delayed by a time interval equal to the propagation time through the delay medium. To conserve space and material, the acoustic beam path may be folded one or several times, as shown in Figure 2. Since the transducers are resonant devices, a solid delay line acts as a bandpass network with a frequency of minimum attenuation in the vicinity of the transducers' resonant frequency.

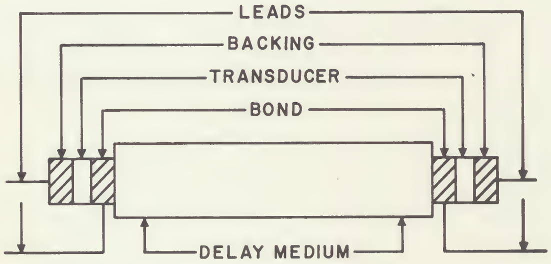


**Figure 1.** Solid Ultrasonic Delay Line

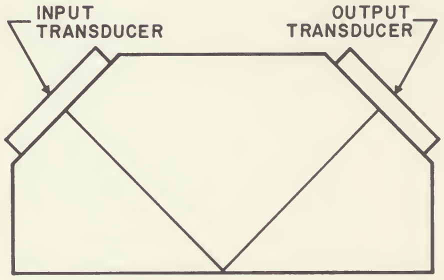


**Figure 2.** Ultrasonic Delay Line with Folded Acoustic Path

### Digital vs. Conventional Delay Lines

In conventional ultrasonic delay lines, the information to be delayed modulates an RF carrier whose frequency is equal to the center frequency of the delay line; the delayed signal is then amplified and detected. This scheme permits operation of the delay line in its most efficient mode, and does not impose strict limits upon bandwidth and dispersion requirements.

If a video pulse is applied to a conventional ultrasonic delay line, its frequency components are essentially analyzed in the time domain, with the higher frequency components delayed less and arriving first (Figure 3); the resulting pulse is highly distorted. Digital delay lines, however, are corrected for this type of distortion, with the result that a delayed video pulse approximates the typical pulse response of the ideal bandpass filter with linear phase shift (see Figure 4). For a delay line with a given center frequency, the optimal video pulse width should be equal to approximately one-half the period of the center frequency. If the line is operating in an RZ mode, the pulse spacing is equal to the pulse width, and the maximum bit rate of the line is equal to the nominal center frequency.

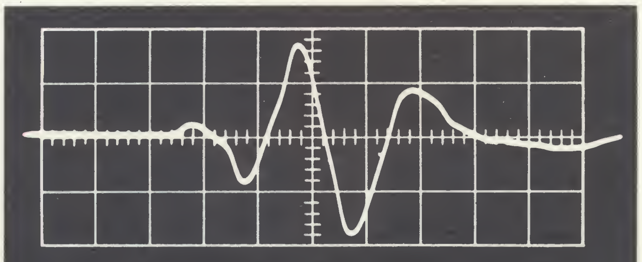

**Figure 3.** Dispersion in Acoustic Delay Line

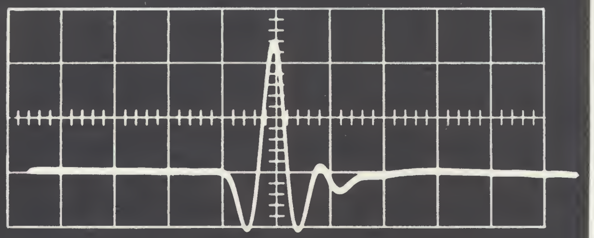

Figure 4. Output Pulse, Non-Dispersive Acoustic Delay Line

## Glass vs. Quartz Medium

Until recently, the standard medium for ultrasonic delay lines has been fused quartz, which combines excellent loss properties over a wide frequency range with good handling and manufacturing characteristics, and which provides a good impedance match with commonly used transducer materials. The major disadvantage of quartz, however, lies in its high temperature coefficient (−70 to −80 ppm/°C). Various glass compositions exhibiting low temperature coefficient and adequate loss characteristics have been developed for use in digital delay lines. These glasses have a temperature coefficient of zero at one specific temperature within the 20 to 50°C range, and a linear change in temperature coefficient on either side of this minimum. Figure 5 illustrates the temperature characteristics of the zero-temperature-coefficient glass used by the Advanced Components Operation of LFE Electronics in the manufacture of digital delay lines.

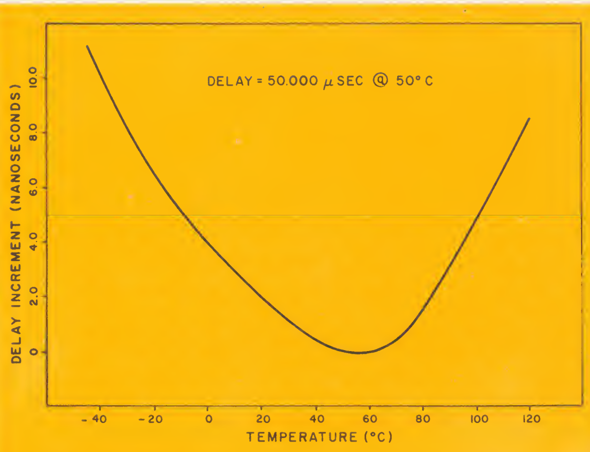


Figure 5. Delay vs. Temperature Characteristics — Zero-Temperature-Coefficient Glass Delay Lines

Besides eliminating the need for close temperature control in most applications, zero-temperature-coefficient glass exhibits an acoustic impedance which closely matches that of quartz transducers. This characteristic yields wide bandwidths and minimizes transducer ringing, which is a major source of distortion. Acoustic losses are somewhat greater than in fused quartz, with the result that the use of zero-temperature-coefficient glass is restricted to relatively short delay lines.

Transducer materials used in solid digital delay lines fall into two categories — crystalline quartz and piezoelectric ceramics. Quartz crystals are relatively low efficiency devices (coupling coefficient = 0.14) with resultant high radiation resistances; since the quartz crystal is essentially a constant current device, changing the load resistance will change the output voltage level. The low dielectric constant of quartz yields low transducer capacities even at very high frequencies. Piezoelectric ceramics, such as barium titanate, lead zirconate titanate (PZT), or lead metaniobate, are characterized by high coupling coefficients (0.7 and above) which result in low radiation resistances. Their very high dielectric constants prevent their application to high frequency delay lines unless special techniques are made use of to limit transducer capacitance.

## DEFINITIONS AND MEASUREMENTS

Most parameters of concern in digital lines — such as capacity and attenuation — are conventional and require no special definitions; however, special characteristics require some elaboration. The waveforms presented below (Figures 6 and 7) illustrate some of these characteristics. Figure 8 outlines a typical test setup for measuring delay, attenuation, and spurious levels.

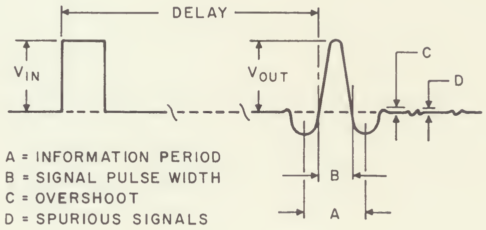


Figure 6. Waveform Definitions — RZ Mode

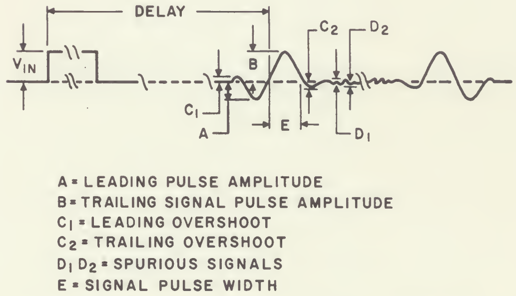


Figure 7. Waveform Definitions — NRZ Mode

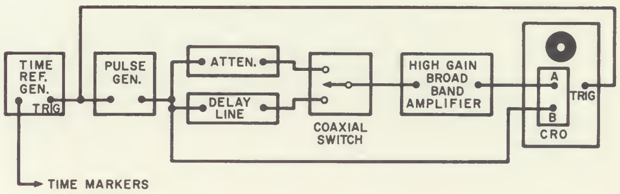


Figure 8. Typical Test Setup for Digital Delay Lines

## APPLICATIONS

In the field of data processing, digital ultrasonic delay lines have found wide application as serial memory elements for bulk and buffer storage, as scratch-pad memories, shift registers and trigger delay devices, or for pulse-shaping purposes. The high storage capabilities, mechanical ruggedness, and electrical and chemical stability of digital ultrasonic delay lines also suggest their utilization in many space, missile and communication applications.

A typical recirculating memory system employing a digital ultrasonic delay line is illustrated in Figure 9.

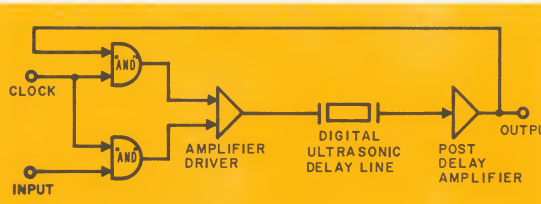


Figure 9. Serial Memory Package Employing Digital Delay Line

## GENERAL CHARACTERISTICS OF DIGITAL DELAY LINES

| | Quartz-Quartz | Ceramic-Quartz | Quartz-Glass | Ceramic-Glass |
|---|---|---|---|---|
| **Delay Range** | 1-1000 μsec | 1-1000 μsec | 1-150 μsec | 1-150 μsec |
| **Bit Rate or Center Frequency Range** | 5-40 Mc | 3-25 Mc | 5-40 Mc | 0.5-25 Mc |
| **Bit Length Range** | 10-100 nsec | 20-150 nsec | 10-100 nsec | 20-1200 nsec |
| **Transducer Capacity Range** | 25-150 pF | 50-10,000 pF | 25-150 pF | 50-10,000 pF |
| **Attenuation Range** | 40-80 db into 50 ohms | 20-60 db into 50 ohms | 30-80 db into 50 ohms | 20-80 db into 50 ohms |
| **Typical Signal/Noise Ratio** | 10-20/1 | 10-20/1 | 15-25/1 | 5-15/1 |
| **Temperature Coefficient of Delay** | −75ppm/°C ±5ppm/°C | −75ppm/°C ±5ppm/°C | See Fig. 5 | See Fig. 5 |
| **Radiation Resistance (Typical)** | 500-10,000 ohms | 1-200 ohms | 2000-8000 ohms | 1-200 ohms |

Note: Digital delay lines are generally encased in metal cans, both for shielding purposes and for mechanical stability. Packages designed for hostile environments or to military specifications can also be provided. A variety of painted or plated finishes are available.

## SPECIFYING DIGITAL DELAY LINES

Specifications should include the following:

(1) Total delay, or total storage capacity, and tolerances
(2) Maximum bit rate
(3) Mode of operation (RZ or NRZ)
(4) Video pulse or bit characteristics: width, amplitude, rise and fall times, etc.
(5) Signal-to-noise ratio
(6) Input and output admittances
(7) Load resistance
(8) Pulse attenuation
(9) Operating temperature range, and stability within that range; in the event that quartz is to be used as the delay medium, state power available for heaters and expected ambient levels
(10) Physical size, packaging, and type of connectors
(11) Environmental requirements

A general description of the application, with schematics of driving and amplifying circuitry, is also useful.

## SPECIAL DIGITAL UNITS

In addition to the conventional digital delay lines described above, the Advanced Components Operation of LFE Electronics offers delay or memory packages for special requirements.

These include:

- Tapped delay lines
- Digital echo lines
- Multiple-channel delay lines
- Adjustable delay lines
- Isothermal quartz delay line packages, incorporating heaters and associated control circuits
- Multipackages incorporating two or more delay lines
- Complete serial memory systems

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